

BIONOMICS OF THE AQUATIC MOTH, *ACENTROPUS NIVEUS*
(OLIVIER),¹ A POTENTIAL BIOLOGICAL CONTROL AGENT
FOR EURASIAN WATERMILFOIL² AND HYDRILLA³

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Abstract.—Batra, S. W. T., Beneficial Insect Introduction Laboratory IIBIII, Agr. Res. Serv., USDA, Beltsville, Maryland 20705.—Larvae of *Acentropus niveus* (Olivier) on watermilfoil in Lake St. Lawrence, N.Y. overwintered in water-filled cocoon-like hibernacula attached to host propagules. Feeding from newly constructed summer shelters on fresh plant growth commenced in June, they produced a single generation of short lived rudimentary-winged aquatic females and winged males which reproduced in July–September. After some feeding, the resulting small larvae entered hibernation in October. In the laboratory, larvae fed on *Myriophyllum spicatum* L., *M. spicatum* var. *exalbescens* (Fernald) Jepson, *Hydrilla verticillata* (L.f.) Royle, *Elodea canadensis* Michx. and *Ceratophyllum* sp. Since diapause apparently is caused by low water temperature rather than by short daylength, this insect may adapt to Florida conditions for possible *Hydrilla* and *Myriophyllum* control. Behavioral details are given, damage to host plants is evaluated and additional host-specificity testing is recommended.

Received for publication 3 June 1977.

Introduction

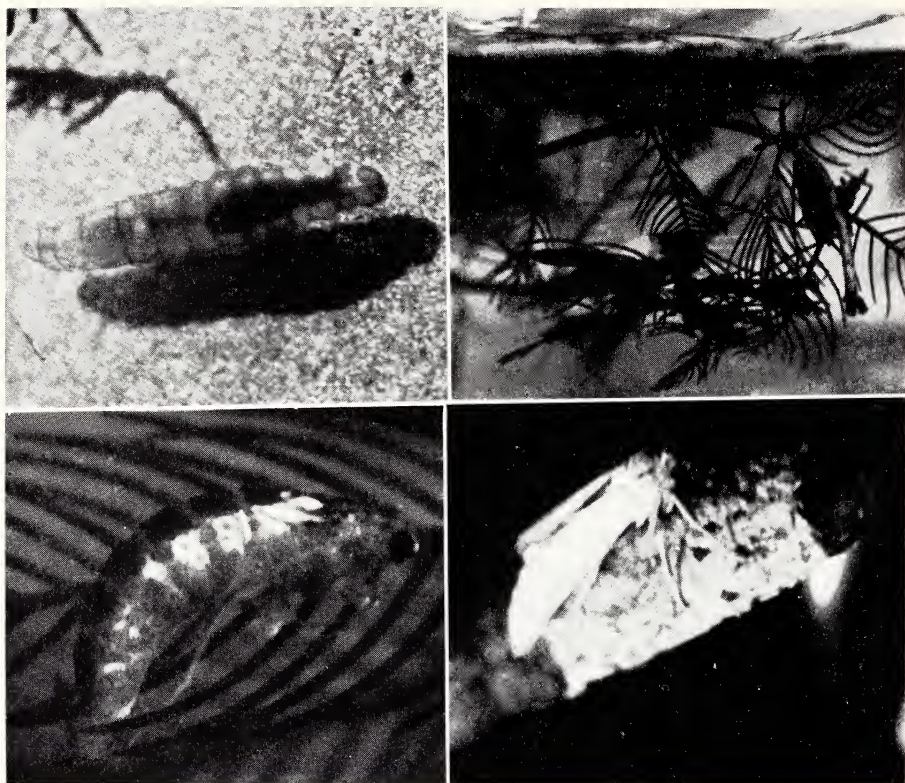
Eurasian watermilfoil (*Myriophyllum spicatum* L.), a submersed aquatic perennial, was first collected in North America (in Chesapeake Bay) in 1902 (Nichols, 1975). Introduced from Europe, it has become a troublesome weed only during the past 20 years, interfering with fishing, causing silting of shellfish beds, hindering navigation and water sports, clogging water intakes, and providing mosquito breeding sites, with consequent depression of property values (Smith et al., 1967; Holm et al., 1969; Spencer and Lekić, 1974). It occupies over 10,000 hectares in the Tennessee Valley Authority reservoirs (Smith et al., 1967), 680 ha in Florida (Blackburn and Weldon, 1967; Spencer and Lekić, 1974); and smaller areas are infested in 20 other states (Nichols, 1975). In the Chesapeake Bay (Maryland), Eurasian watermilfoil occupied 81,000 ha by the early 1950's (Spencer and Lekić, 1974); however, it suddenly declined there by 95% after 1966. This decline has been attributed to algal blooms or pathogens (Bayley et al., 1968) and to increased water turbidity (Southwick and Pine, 1975). Watermilfoil is also able to propagate explosively, for example, in Currituck Sound (North

Carolina), where in one year it extended its range from about 1,600 ha to some 30,000 ha (Nichols, 1975). Axillary vegetative buds and fragmentation of stems are the primary means of reproduction, although the seeds may be carried for longer distances. A 5 cm stem fragment may root and grow 1.5 m in one season; in the second year multiple stems arising from the rooted base may reach a length of 5 m (Smith et al., 1967). It grows well at pH values between 5.8–9.7 and tolerates brackish water (to 15 ppt salt or 40% sea water; Anderson et al., 1965).

Although it is occasionally eaten by waterfowl (Martin and Uhler, 1951) and it shelters small aquatic organisms (Krecker, 1939), Eurasian water-milfoil is generally considered a noxious weed. Periodic lowering of the water table is the most effective control measure, but mechanical harvesting and herbicides are also used (Smith et al., 1967). Due to the cost, impracticality, impermanence or hazardous nature of these methods, biological control agents relatively specific to *M. spicatum* are being sought in Eurasia (Lekić, 1970a, b; Lekić and Mihajlović, 1970; Baloch et al., 1972; Spencer and Lekić, 1974). One of the more promising insects is a European nymphuline moth, *Parapoynx stratiotata* L. (Lekić, 1970a), under study by the USDA-ARS for possible use in watermilfoil control in North America (N. R. Spencer, pers. comm.). Another is *Acentropus niveus* (Olivier) which is a possible biological control agent for watermilfoil in Florida. Studies relating to its potential use were begun in 1975.

The life history and morphology of *A. niveus*, a univoltine schoenobiine moth, were intensively studied in Europe by Ritsema (1878), Nigmann (1908) and Berg (1942); many details, therefore, will not be repeated here. In Europe it occurs from Scandinavia to the Caspian Sea in fresh or brackish water (Hannemann, 1967). It was first collected in North America in 1927 at Montreal (Sheppard, 1945). For the next 20 years, it was repeatedly and sometimes abundantly found in the St. Lawrence River and its tributaries, and in Lakes Ontario and Erie (Judd, 1950). By 1952 it was in Massachusetts (Treat, 1954; 1955), and there are specimens taken in 1963 at Middleton, Wisconsin, in the United States National Museum. This seems to be an accidentally introduced species that is now rapidly extending its range (also see Lange, 1956).

Acentropus niveus is an unusual moth in several ways: (1) the eggs, some adults and caterpillars are strictly aquatic; (2) larvae lack gills and the rudimentary spiracles are closed; (3) special hibernacula are made by the overwintering larvae; (4) the pupa obtains oxygen through spiracles, which is released into the cocoon from holes made in the aerenchyma of the host plant to which it is attached; (5) some females are fully winged but others from the same population may have rudimentary wings; and (6) the rudimentary-winged females rely on plastron respiration and swim by means of hair brushes on the legs.



Figs. 4-7. Living developmental stages of *Acentropus niveus* (not to same scale). 4. Larva crawling freely through water; the dark gut contents are clearly visible. 5. Larval feeding shelters on *Myriophyllum*. 6. Vestigial-winged female in water. The bright patches are caused by reflection from the air film trapped among the body scales. 7. Male in characteristic resting position near the water surface on protruding *Myriophyllum* stem. Note extended maxillary palpi.

summer shelters of silk and bits of leaves from which they feed for about 5 weeks (Figs. 1, 5). They periodically leave these shelters and crawl freely about (or occasionally carry detached shelters) while spinning a silken thread (Fig. 4). The larval stage, which overwinters, lasts about 10.5 months; the pupal stage lasts about 25 days at 20–22°C (Nigmann, 1908).

In Europe, larvae have been collected or reared from *M. spicatum* L.; *Elodea canadensis* Michx., *Potamogeton crispus* L., *P. perfoliatus* L., *Ceratophyllum demersum* L. and *Trapa natans* L. (Ritsema, 1878; Nigmann, 1908; Berg, 1942). In North America, they were found on *C. demersum* and *Elatine triandra* Schkuhr (Judd, 1950; Treat, 1955). Additional North American hosts reported here are *Elodea canadensis* Michx., *M. spicatum*

var. *exalbescens* (Fernald) Jepson, *M. spicatum*, and in the laboratory they were reared on *Hydrilla verticillata* (L.f.) Royle, another major introduced aquatic weed pest in Florida.

Field Studies

A population of *A. niveus* was studied at the St. Lawrence River near Massena, N.Y. (at Lake St. Lawrence, near Long Sault Dam). Larvae were feeding on *M. spicatum* var. *exalbescens* that was growing densely in a shallow freshwater cove near Barnhart Marina (Robert Moses State Park).

The life cycle in the St. Lawrence River differs slightly from that in Europe (see Berg, 1942; Nigmann, 1908). On 16 June 1976, the watermilfoil was not visible at the surface of the cold, murky water (18°C, 15 cm below the surface, 15°C at 2 m depth). Medium-sized to large overwintered larvae were feeding on young axillary shoots (turions) springing from short, rooting broken bits of old watermilfoil stems (propagules), that were covered with silt and filamentous algae and were lying on the mucky bottom (at 2 m). A random sample of 20 such propagules (mean length 10.6 cm; range 2.5–28.0 cm), with a mean 19.5 (4.0–56.0) leaves, bore $\bar{x}$ 2.5 (0–10) larval shelters. Some of these larvae began to pupate within ten days in the laboratory and an adult male emerged July 7; but no cocoons or adults were found in the field. Adults have been collected as early as June 14 at Lake Erie (Judd, 1950), and in Europe (Netherlands and Germany) they begin to appear in late May (Ritsema, 1878; Nigmann, 1908). According to Berg (1942), larvae break diapause and begin feeding at 12–14°C. This water temperature was reached by mid-May at Esrom Lake, Denmark. When adults first appeared there in late June, the water temperature had reached 21°C. In Lake St. Lawrence, the water reached 12–14°C about three weeks later, by June 1, and 21°C on August 1, a month later than at Esrom Lake, which would explain the relative delay in the appearance of adult *A. niveus* at Lake St. Lawrence.

By 21 July 1976, the water temperature was 20°C at 15 cm below the surface and 18°C at 2 m depth at Lake St. Lawrence. The watermilfoil propagules had rooted and grown rapidly to a length of about 1.5 m but the plants had not quite reached the surface. Larvae and pupae were collected, but adults were not seen, although some emerged after a few days in the laboratory.

By 5 August (1975), the 2–2.5 m long strands of watermilfoil had reached the surface. Numerous *A. niveus* males were resting on the emergent flowering spikes. Larvae and pupae were exclusively on the topmost 5–25 cm of the watermilfoil stems, among the youngest leaves and in a relatively warm zone of sunlit surface water (30°C at 15 cm). The plants formed dense stands in water 1–3 m deep. The matted, floating apices shaded the

senescent, marl and silt covered lower stems and old leaves in cooler (21°C) water. The distribution of the insects was uneven; for instance, a sample of the upper 30 cm of 50 watermilfoil stems from one location yielded 10 pupae, but a similar sample taken 30 m distant contained only one pupa. This may be the result of restricted egg dispersal by the rudimentary-winged females. Winged females were not found in 1975 or 1976 at Lake St. Lawrence, although they were common in Lake Erie (Judd, 1950) and Massachusetts (Treat, 1955). Males spent the day resting 0.5–1.0 cm above the water surface on protruding watermilfoil stems or flowering spikes (Fig. 7). At dusk and during the night, they flew just above the water surface, skittering in circles for about 30–60 sec, alternating with rest periods of several minutes.

By 17 September 1976, most plants were no longer blooming, and the water temperature was 19°C at 15 cm and 18°C at 2 m depth. Adult *A. niveus* were still emerging and young larvae 2–4 mm long were eating leaves near the surface. Eighteen of a random sample of 37 entire watermilfoil plants each bore 1–3 larval or pupal shelters. Twelve of the larvae were on leaves, and 6 (and all pupae) were on stems. Distribution per stem was as follows: uppermost 2 cm, 7 larvae; next 2–4 cm, 9 larvae; 4–6 cm, 1 larva; 7–17 cm, 1 pupa; 18 cm, 1 larva; 25 cm, 1 pupa; below 25 cm, no *A. niveus*. No mature larvae were found and the pupae were evidently the last of the season.

The field site was visited for the final time on 14 October 1976, during a snowstorm. Although the plants still reached the surface, the senescent, fragile stems were beginning to fragment, partly as a result of rough waves. Mean water temperature was 13°C. A random sample of 37 apical 1 m lengths of watermilfoil yielded 22 shelters of 3–4 mm long larvae; no pupae or larger larvae were found. Most of the shelters were on main stems but some were on leaves or overwintering buds. These previously undescribed shelters (hibernacula) were firmly constructed of thick, tough layers of brownish silk and watermilfoil leaflets (Figs. 2, 3). They resembled cocoons rather than the flimsy, temporary summer feeding shelters (Fig. 1). However, unlike the air filled cocoons, they were filled with water. The hibernating larvae were contracted, of a grayish-yellow translucent color, and had empty guts and air-filled tracheae. Unlike feeding larvae, they were unresponsive to light or touch. Evidently these diapausing larvae survive freezing because the water level at the study area is 2–3 m lower in winter and the water freezes to a depth of 1–6 m, which would include the watermilfoil beds.

Laboratory Studies

Larvae and pupae from Lake St. Lawrence were established in a rearing room at Beltsville, Md. Unless otherwise stated, material was kept

in fresh water in a single 20 gal (72.7 liter) aquarium at 18–27°C with a long day length schedule (16 h L: 8 h D). Several species of food plants were provided, primarily *M. spicatum* var. *exalbescens* (eaten), but also at times additionally *M. spicatum* from the Chesapeake Bay (eaten), *Hydrilla verticillata* (eaten), *Elodea canadensis* (eaten), *Ceratophyllum* sp. (eaten), *Myriophyllum brasiliense* Cambess. (not eaten), *Azolla* sp. (not eaten), *Lemna* sp. (not eaten), *Spirodela* sp. (not eaten), *Salvinia* sp. (not eaten), *Pistia stratiotes* L. (not eaten), *Alternanthera philoxeroides* (Mart.) Griseb. (not eaten), *Eichhornia crassipes* (Mart.) Solms (not eaten), and filamentous algae (not eaten). The larvae readily transferred to and ate *Hydrilla verticillata* even when *M. spicatum* was available. Development to the adult stage and egg production on *Hydrilla* appeared normal.

Feeding larvae damaged the watermilfoil by girdling the leaves or stems and by eating leaflets. When 5 large (8–10 mm) larvae were each kept on a 10 cm strand of watermilfoil in petri dishes for 8 days at 23°C, they girdled, broke off and dropped a mean of 15 (range 8–23) entire leaves and also $\bar{x}$ 101 (range 67–180) leaflets. Many additional leaflets that were eaten rather than dropped were represented by some 1,000 frass pellets per larva; food passed through the entire gut in 1.5 h. One of the five larvae girdled the stem and 1–4 shelters per larva were made. However, the watermilfoil strands elongated by $\bar{x}$ 7 (range 0.5–17.0) cm during this time.

The pale greenish-yellow transparent larvae fed from their shelters until leaves within reach were eaten (Fig. 1). The leaves or leaflets were often drawn by feeding larvae toward the shelters or were girdled. When nearby food was depleted, the larvae left their shelters, usually in the mid-morning, and crawled with a somewhat looping motion (covering 1–2.5 cm per minute) until finding suitable food. A new shelter was made before feeding resumed, but occasionally old shelters were re-entered and used again. Larvae ceased feeding and remained quiescent in shelters for 2 or 3 days before cocoon-spinning in the shelters and pupation. Larvae kept on watermilfoil in brackish water from the Chesapeake Bay near Annapolis, Md., developed normally to adults.

Construction of a summer shelter required 1.5–2.0 h at 23°C. The larva first chewed the stems or leaf rachis, which roughened the surface, permitting secure silk attachment. Stiff leaflets were also partially eaten, which increased flexibility. A silken web was spun (about 18 oscillations per minute) to adjacent leaflets, which were gradually drawn over the larva. Larvae continued to eat and often reversed positions during web construction. Frass was excreted through the open caudal end of the shelter; plant detritus, frass, and snail eggs in the shelter were picked up by the mandibles and dropped outside. Algae-covered leaves or stems were avoided. Air bubbles released from the aerenchyma and caught in the web

were also expelled. Enemies include the planarian, *Dugesia* sp., which ate the eggs and dytiscid larvae that attacked larvae. Larvae were unaffected by guppies sharing the aquarium.

Groups of 7 diapausing larvae in hibernacula on watermilfoil taken from the St. Lawrence River in October were each given one of three treatments: (1) freezing in an outdoor pool for 35 days; (2) maintenance at 25°C in the rearing room aquarium at long (16 h) daylength; (3) maintenance at a 21°C laboratory room aquarium at prevailing 8 h winter daylength. The frozen larvae (treatment 1) broke diapause, made summer shelters and began feeding on the sprouting watermilfoil turions within 20 days after being brought into the rearing room. Those kept without prior freezing in the rearing room (2) or laboratory (3) first broke diapause within 15 days. Evidently diapause is maintained by cool temperature rather than by short daylength. Although the diapausing larvae and the feeding larvae had the same head capsule width (about 0.6 mm), the feeding larvae with distended guts were much longer (6.0–6.5 mm) than the empty, shrunken 3.5 mm larvae in hibernacula (Fig. 3).

Discussion

Acentropus niveus may be of some value as a biological control agent for *Myriophyllum spicatum* and *Hydrilla verticillata* in North America. Multiple-choice and starvation tests must be performed to determine the degree of host-specificity or preference in order to avoid possible damage to valuable aquatic plants. For such testing, numerous insects must be maintained to ensure that enough of the short-lived adults simultaneously emerge for mating. Laboratory studies reported here indicate that this insect may become multivoltine in Florida, since adults emerged sporadically throughout the winter in the rearing room, although there were not enough to mate and produce new generations. The question remains as to why it has not extended its range into southern Europe. Perhaps a potential second generation would have been destroyed by frost in a transition zone, although it may have the ability to survive further south, in the subtropics or tropics. Due to the vigorous growth of the target plants, a dense population of *A. niveus* would be needed to do any significant damage. The breakage of stems by feeding larvae creates new propagules which may actually aid in spreading the plant. The possible combination of *A. niveus* with a plant pathogen introduced through feeding wounds may be worth investigating.

Acknowledgments

I thank Robert D. Conner of the St. Lawrence Power Project for information regarding annual water temperatures, water level fluctuations, and

ice cover. Mike Millarney and Marian Cousineau of Robert Moses State Park kindly provided some facilities, and D. C. Ferguson verified my identifications.

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Footnotes

¹ Lepidoptera: Pyralidae.

² *Myriophyllum spicatum* L. (Haloragidaceae).

³ *Hydrilla verticillata* (L.f.) Royle (Hydrocharitaceae).